National Aeronautics and Space Administration

GRADES **5-8**

Space Shuttle Tiles

Aeronautics
Research
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Museum in a BOX Series

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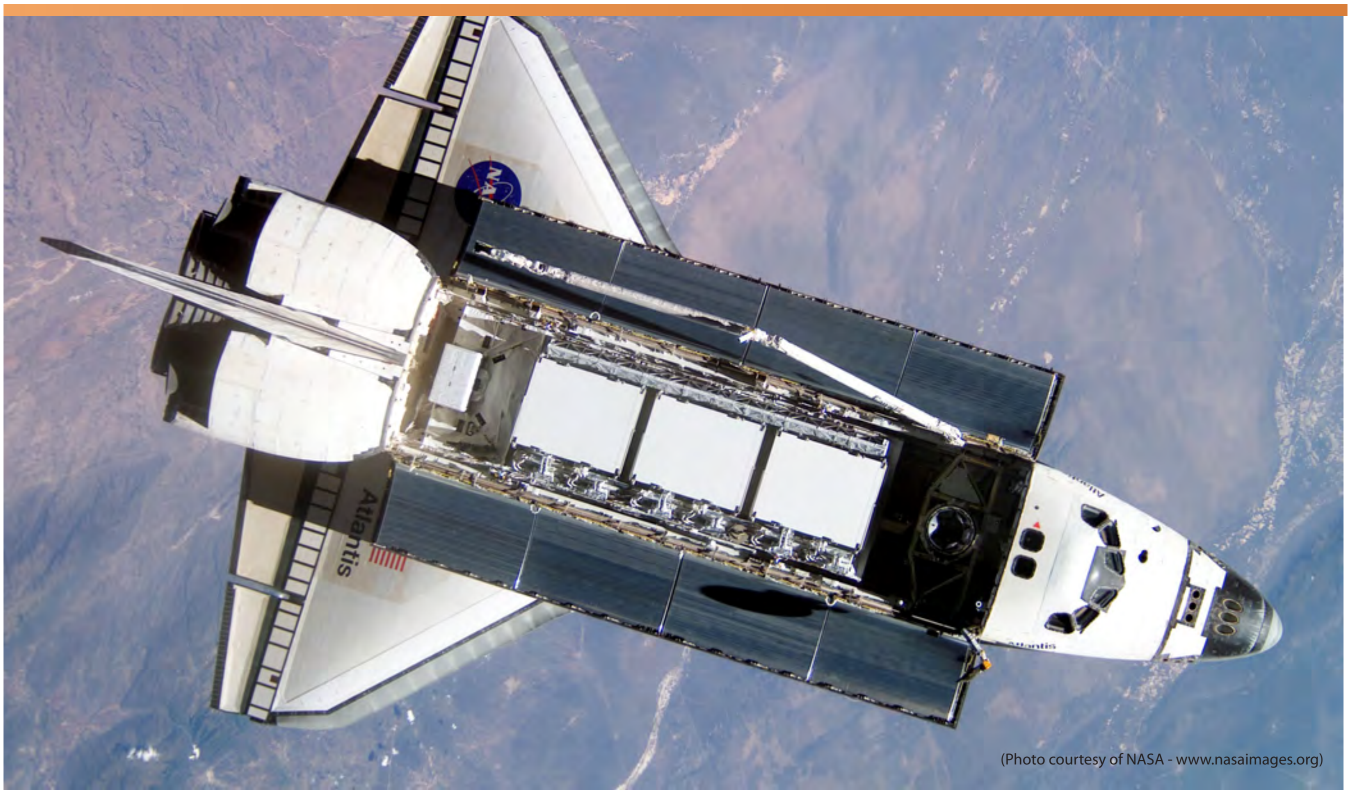

Img. 1 The Space Shuttle Atlantis in orbit.

Space Shuttle Tiles

Lesson Overview

This activity is divided into 2 parts—Activity1 Shuttle Tile Density and Activity 2 Thermal Properties. During the first task the students will determine the density of the shuttle tile included in the MIB. The students will then do Activity 2 to demonstrate the thermal properties of a shuttle tile. Use the background material as a lead into the activity.

SAFETY NOTE FOR SHUTTLE TILE:
The silica material in shuttle tiles is not classified as hazardous either by Federal SARA or CERCLA standards. However, material from the silica fiber layer can cause temporary irritation of the throat and/or itching of the eyes and skin so that touching a bare tile should be avoided. For your convenience, the tile is sealed in a protective plastic wrapping. The plastic wrap should not be removed. Never touch the shuttle tile. More information is available through MSDS (www.MSDS.gov).

Objectives

1. Determine density of a shuttle tile and compare its density with those of other materials
2. Students will determine the thermal properties of 2 different cups of hot water.

Materials:

Included in MIB

Space Shuttle tile
Food scale

Provided by User

Foam cups (1 per group)
Paper cups (1 per group)
Hot water
Thermometers (1 per group)
Two balls of approximately the same size, but different weights, such as a baseball and a tennis ball

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Time Requirements: 1 hour

Background

Shuttle Tiles


(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.

A key to a successful thermal protection system for the Space Shuttle depends on two things—light weight and the ability to withstand the high temperatures of reentry.

When the space shuttle de-orbits and begins to return to Earth, it faces a serious problem due to frictional heating. Protecting the shuttle and the crew from such heat is very important. When the shuttle reenters Earth's atmosphere at about 400,000 feet or about 122 km, it is traveling at about 25 times the speed of sound (Mach 25). It uses the friction of reentry to slow the shuttle down, but in doing so it pays a price in the form of frictional heating. Temperatures on the shuttle reach several thousand degrees. If the shuttle had a metal exterior like an airplane, it would be burn up due to the heat produced by the friction.

The tiles on the shuttle provide a means for thermal protection.

There are some 24,300 tiles that measure about six inches long on each side (15.25cm) and vary in thickness from 1 to 5 inches (2.54 to 12.7 cm) depending on where they are attached. They are made up of what is called a porous silicon material that is very light and extremely heat resistant. There are two main types of tiles, one a black-coated tile called HRSI for High-Temperature Reusable Surface Insulation tile. These tiles can withstand up to 2,300 degrees F (1,260 degrees C). They cover the bottom of the shuttle, areas around the forward windows, and several other key areas. The densities of these tiles range from 9-22 pounds per cubic foot.

(Photo courtesy of NASA - www.nasaimages.org)

The second type are white-coated tiles and are LowTemperature Reusable Surface Insulation (LRSI). They are made to insulate the shuttle up to 1,200 degrees F (650 degrees C). These tiles are usually larger and thinner, 8 inches long on each side (20.3cm) and from less than a half inch (1 cm) thick up to 1 inch (2.54 cm) in thickness. The densities range from 9 to 12 pounds per cubic foot.

The making of tiles begins with pure silica that comes from refined sand. This material is formed in fibers and mixed with pure water and other chemicals and then poured into a mold where the excess water is squeezed


(Photo courtesy of NASA - www.nasaimages.org)

A close-up of the tile numbering system.

out. This is then taken to the largest microwave oven in America located at the Lockheed Space Operations plant in Sunnyvale, California. After this they are treated in an oven at a temperature of 2,350 F (1,288 C). This process fuses the fibers without actually melting them.

The two types of tiles are essentially the same except for the coatings and cut. No two tiles are exactly alike. They fit by being trimmed to an exact size depending on its location on the shuttle. The tiles form the ultimate "jigsaw puzzle", only in this case, each piece is numbered so its location is easy to find.

Activity 1 Shuttle Tile Density

GRADES 5-8

Materials:

In the Box

Space Shuttle tile
Food scale

Supplied by user

A Baseball
A Tennis ball

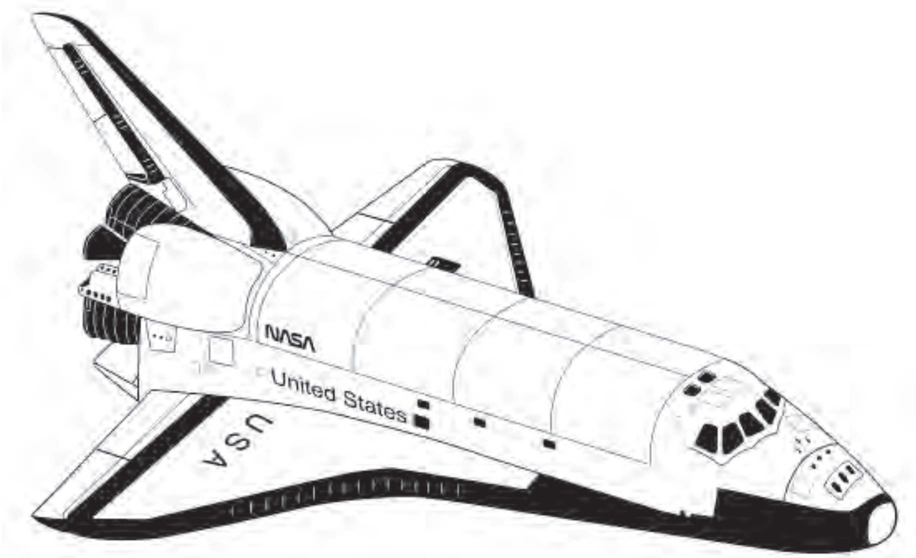
Worksheets

Shuttle Tile Volume (Worksheet 1)

Reference Materials

None

Time Requirement: 30 minutes



Img. 8 An artist's rendering of the Space Shuttle.

Objective:

Discover how material densities affect a Space Shuttle launch.

Activity:

1. Toss the baseball and tennis ball in your hands. Ask the students to describe what is different about the balls. Infer how the difference in weight (and thus the densities of the balls) would affect how the balls are thrown. Students may say that you need more force to throw the baseball than to throw the tennis ball the same distance. Lead the students to discuss how the force exerted on the balls is proportional to the work done in throwing the balls and thus, the amount of energy. They should arrive at the conclusion that it takes more energy to move a heavier ball than one of less weight.

2. Discuss how you would find the densities of the balls (mass/volume). They both have the same approximate volume, but because the baseball has more mass (and thus more weight), it is more dense.

3. Explain that engineers must consider many factors when designing and choosing materials for various purposes. Show the students the picture of the space shuttle orbiter. Point out the tiles and ask the students to infer the function of the tiles. (To protect the shuttle (and thus the shuttle occupants) from heat that is produced (from friction) as the shuttle moves through the atmosphere.) Show the students the space shuttle tile. What would be some characteristics of materials that engineers would find desirable for a shuttle tile? As students name characteristics, write these on the board or on chart paper. (Low cost, safe, durable, high thermal insulating ability, low density.) Now, go back to the analogy with the tennis ball and baseball – why would good material for a space shuttle tile be low density? (Less weight takes less energy (and less cost) to launch into space.) Pass the shuttle tile around. The tile is very fragile and students should be instructed on how to handle the tile carefully. ** CAUTION – The tile must stay in the plastic bag! ** Now we will determine the density of the space shuttle tile and compare it to the density of other objects.

4. Perform the following density calculations.
**Note: Numbers in the following calculations are for example only. Class calculation will vary by individual tile.*

a. Determine the volume of the shuttle tile. Measure its length, width and height then multiply these numbers to determine the volume in cubic inches.

$$\text{length} \cdot \text{width} \cdot \text{height} = \text{volume}$$

$$6 \text{ in} \cdot 6 \text{ in} \cdot 3 \text{ in} = 108 \text{ in}^3$$

b. Weigh the shuttle tile.

Tile weight: 0.8 lb

c. Determine the density of the shuttle tile

$$\frac{\text{Weight}}{\text{Volume}} = \text{Density (lbs/in}^3) \qquad \frac{.08 \text{ lb}}{108 \text{ in}^3} = 0.0074 \text{ lbs/in}^3$$

d. Compare the density of a shuttle tile with the density of other materials. The density of several common materials are listed below. Convert the density measurement for each of these materials to pounds/cubic inch. To do this, divide the measurement by the number of cubic inches in a cubic foot, which is 1,728 in3.

Aluminum

$$\frac{165 \text{ lb/ft}^3}{1{,}728 \text{ in}^3/\text{ft}^3} = 0.0955 \text{ lbs/in}^3$$

Iron

$$\frac{495 \text{ lb/ft}^3}{1{,}728 \text{ in}^3/\text{ft}^3} = 0.2865 \text{ lbs/in}^3$$

Material	Density lbs/ft^3	Density lbs/in^3
Metal		
Aluminum	165 lbs/ft^3	0.0955 lb/in^3
Iron	495 lbs/ft^3	0.2865 lb/in^3
Gold	1204 lbs/ft^3	0.6968 lb/in^3
Woods		
Pine	26 lbs/ft^3	0.0150 lb/in^3
Oak	59lbs/ft^3	0.0341 lb/in^3
Shuttle Tile	--	0.0074 lb/in^3

f. Arrange the items above including the shuttle tile from least density per cubic inch to highest density.

Answer: 1. Tile 2. Pine 3. Oak 4. Aluminum 5. Iron 6. Gold

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

• Abilities necessary to do scientific inquiry

• Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

• Science and technology in society

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

• Understand numbers, ways of representing numbers, relationships among numbers, and number systems

• Understand meanings of operations and how they relate to one another

• Compute fluently and make reasonable estimates

ALGEBRA

• Represent and analyze mathematical situations and structures using algebraic symbols

• Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

• Understand measurable attributes of objects and the units, systems, and processes of measurement

• Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

• Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

• Problem Solving

• Communication

• Connections

• Representation

Activity 2 Thermal Properties

GRADES 5-8

Materials:

In the Box

Space Shuttle tile

Supplied by user

Foam cups (1 per group)

Paper cups (1 per group)

Hot water

Thermometers (1 per group)

Worksheets

Thermal Properties of a Paper and Styrofoam Cup (Worksheet 2)

Reference Materials

Figure 1

Time Requirement: 30 minutes

Activity:

1. Explain to the students that heat is a form of energy that we refer to as thermal energy, while conduction is the flow of energy from one object to another. Emphasize that heat energy always moves from a warmer object or area to a cooler object or area. An example is an ice cube that you hold in your hand.The heat energy moves from your hand to the ice cube causing it to melt. Many students think that the cold is leaving the ice cube and entering their hand. (That is certainly what it feels like!) However, what is really happening is that thermal energy is leaving your warm hand and going to ice cube.

Some objects have high thermal conductivity, meaning thermal energy transfers more quickly between the objects. Other objects have a lower thermal conductivity and do not transfer thermal energy as well. Many students believe that objects such as blankets and sweaters actually generate heat. They do not. Sweaters and blankets are good insulators. They do not allow heat to easily leave your body. They keep you warm by restricting heat flow between your body and the environment, not by generating heat.

2. Refer to the list of desirable shuttle tile characteristics that was generated earlier. We have already discussed that the tiles need to have a low density. Another characteristic of the tile is that it must be a good thermal insulator. Thermal insulators do not allow heat to flow easily from one material to another. The friction between the shuttle and the atmosphere generates an enormous amount of heat. The tiles are good insulators and they protect the shuttle from the heat. Compare and contrast the terms "insulator" and "conductor." Draw a chart on the board or on chart paper and list materials known to students as good insulators of heat and good conductors of heat. Record all answers – even those that are incorrect.

3. Explain to the students that they will be working in groups to determine the thermal properties of paper and Styrofoam cups. First ask the students to discuss with their partners what they already know about paper and Styrofoam cups.

4. Ask the students to use their background knowledge of the cups to create a hypothesis regarding which cup will keep water warm the longest – paper or Styrofoam? Students should record their hypothesis on their Thermal Properties of a Paper and Styrofoam Cup worksheet.

5. Ask the students to design an experiment to test their hypothesis. Explain that they will be given a paper cup and a Styrofoam cup and a thermometer. What will the variables be? What will the procedure be? Students should discuss their experimental design with their partners and record the variables and procedure on their worksheet. Go over their procedures. The recommended procedure is as follows:

   a. Pour an equal amount of hot (not boiling) water into each cup.

   b. Measure and record the temperature of the water in each cup.

   c. After 1 minute, measure and record the temperature of the water in the cups. Each team member should also feel the outside of the cup.

   d. Repeat Step 3 every minute for ten minutes.

   e. If possible, have the students determine how long it will take for the temperature of the water in both cups to reach the same temperature.

6. Students should begin the experiment. **CAUTION: Students should be instructed to use care when working with hot water.** Students should record their data in the data chart provided in the handout, or they can create their own data chart. Students should also answer the analysis questions and write a conclusion summarizing their findings.

7. Refer back to the chart the class created comparing insulators and conductors. Are there any corrections to be made? Be sure that Styrofoam and Shuttle Tiles are listed as insulators.

Discussion Points:

1. Explain why you would choose a Styrofoam cup to keep your cold drink cold during the summer?

2. Explain how the space shuttle tile is able to protect the shuttle from the heat when re-entering the earth's atmosphere. Have them use the terms: thermal energy, conductivity, and heat transfer. *A possible answer might be that thermal energy is transferred to the shuttle tile due to air friction in reentry. The shuttle tile has a very low conductivity and therefore does not allow the thermal energy to be transferred through it to the shuttle. Refer to the conductivity rate in the Some Specifics of Shuttle Tile chart Fig. 1.*

3. What is meant by the term density?

4. What are characteristics of low density materials?

5. Have students identify and classify materials in their homes as either conductors or insulators. Are there any common characteristics among the materials in either group? What makes a material a good conductor or insulator?

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• Communication

• Connections

• Representation

Glossary

Acceleration:
is the rate of change of velocity. An object is accelerating if it is changing its velocity.

Energy:
is the capacity for doing work. You must have energy to accomplish work - it is like the "currency" for performing work. To do 1000 Joules of work, you must expend 1000 Joules of energy.

Friction:
is the surface resistance to relative motion, as of a body sliding or rolling.

Joule:
is the unit of energy equal to the energy exerted by a force of one Newton acting to move an object through a distance of one meter.

Kinetic Energy:
is the energy of motion

Mass:
is a measurement of how much matter there is in a body.

Newton:
is the unit of force equal to the force required to cause a mass of one kilogram to accelerate at a rate of one meter per second squared.

Power:
is the rate of doing work or the rate of using energy, which are numerically the same. If you do 100 Joules of work in one second (using 100 Joules of energy), the power is 100 Watts.

Work:
refers to an activity involving a force and movement in the direction of the force. A force of 20 Newtons pushing an object 5 meters in the direction of the force does 100 Joules of work.

Reference Materials

Fig. 1 Some Specifics of Shuttle Tile

Some of the specifics of the shuttle tile:	
Density	9 lb/ft^3
Specific heat	.15 BTU/lb-°F
Thermal conductivity	.028 BTU/ft-hr-°F at 70°F and 1 atm .073 BTU/ft-hr-°F at 2000°F and 10^{-4} atm
Maximum reuse temperature	>2300°F
Maximum single use temperature	2800°F
Reusability at 2300°F	>100 missions

MUSEUM IN A BOX

Student Worksheets

Worksheet 1 Shuttle Tile Volume

1. Determine the volume of the shuttle tile. Measure its length, width and height then multiply these numbers to determine the volume in cubic inches.

length • width • height = volumne

in • in • in = in^3

2. Weigh the shuttle tile.

Tile weight: lb

3. Determine the density of the shuttle tile

$$\frac{\text{Weight}}{\text{Volume}} = \text{Density (lbs/in}^3) \qquad \frac{\quad \text{lb}}{\quad \text{in}^3} = \quad \text{lbs/in}^3$$

4. Compare the density of a shuttle tile with the density of other materials. The density of several common materials are listed below. Convert the density measurement for each of these materials to pounds/cubic inch. To do this, divide the measurement by the number of cubic inches in a cubic foot, which is 1,728 in^3.

Aluminum

$$\frac{165 \text{ lb/ft}^3}{1{,}728 \text{ in}^3\text{/ft}^3} = \quad \text{lbs/in}^3$$

Material	Density lbs/ft^3	Density lbs/in^3
Metal		
Aluminum	165 lbs/ft^3	lb/in^3
Iron	495 lbs/ft^3	lb/in^3
Gold	1204 lbs/ft^3	lb/in^3
Woods		
Pine	26 lbs/ft^3	lb/in^3
Oak	59lbs/ft^3	lb/in^3
Shuttle Tile	--	lb/in^3

5. Arrange the items above including the shuttle tile from least density per cubic inch to highest density.

1.
2.
3.
4.
5.
6.

Worksheet 2 Thermal Properties of a Paper and Styrofoam Cup

Hypothesis: If hot water is placed into paper and Styrofoam cups, then...

____

Independent Variable: ____

Dependent Variable: ____

Procedure: ____

____

____

____

____

Thermal Properties of a Paper and Styrofoam Cup

Paper Cup		Styrofoam Cup	
Time in Minutes	Temperature	Time in Minutes	Temperature
Starting Temperature			
1 minute		1 minute	
2 minutes		2 minutes	
3 minutes		3 minutes	
4 minutes		4 minutes	
5 minutes		5 minutes	
6 minutes		6 minutes	
7 minutes		7 minutes	
8 minutes		8 minutes	
9 minutes		9 minutes	
10 minutes		10 minutes	
Average		Average	

Worksheet 2 Continued

Analysis:

1. Which cup loses heat more quickly?

2. What might account for the differences between the cups?

3. What was the percent of the original temperature in each cup? As an example, if the original temperature was 100° and at the end of 10 minutes it was still 100° it would be 100 percent; however if it was only 90°, it would only be 90 percent of the original temperature.
What is the percent of the original temperature in the paper cup ____________
and Styrofoam cup___________?

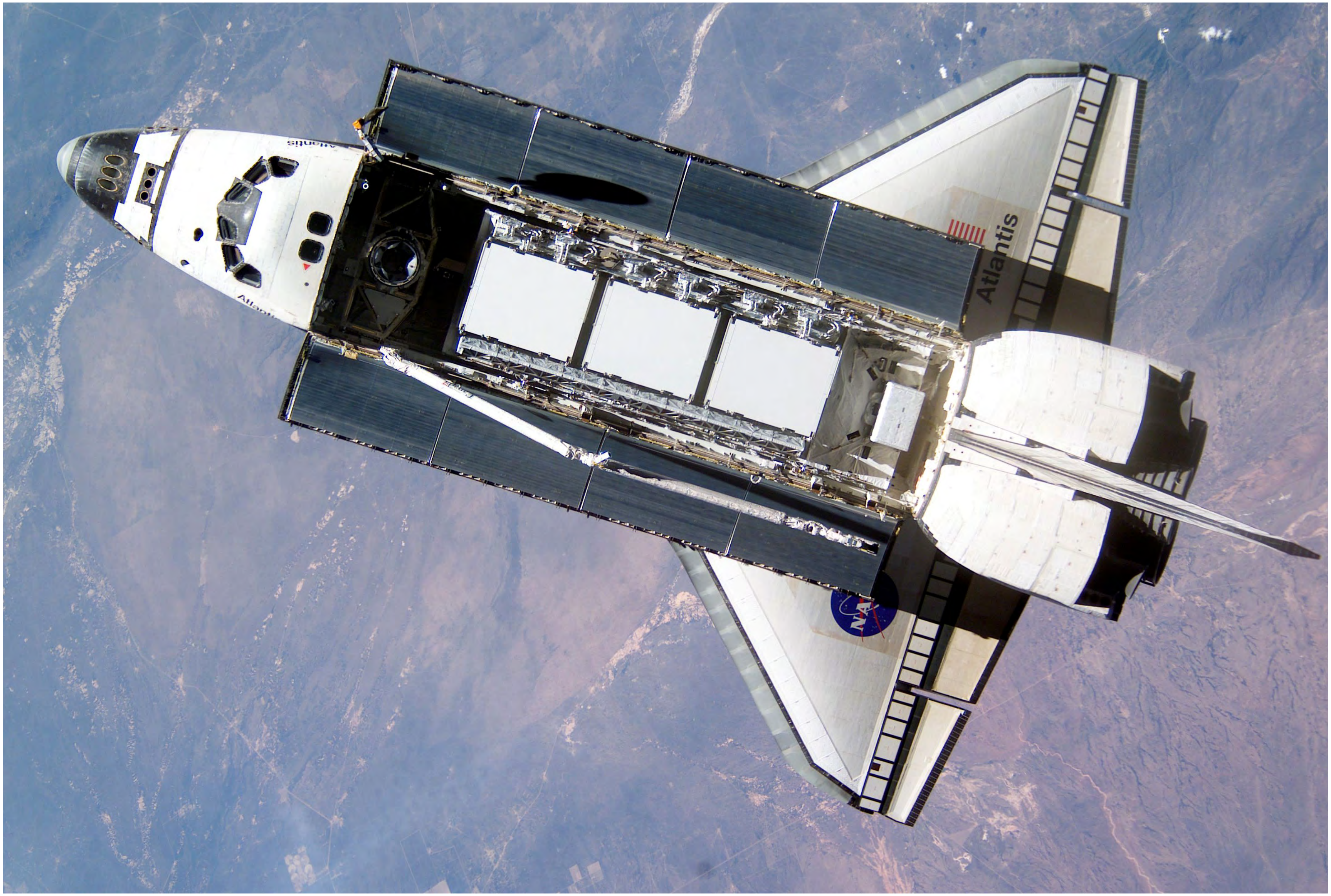
4. What might be some ways to reduce the thermal conductivity even more?

5. If you put cold water in the cups instead of hot water would the temperature change be the same?

Conclusion:

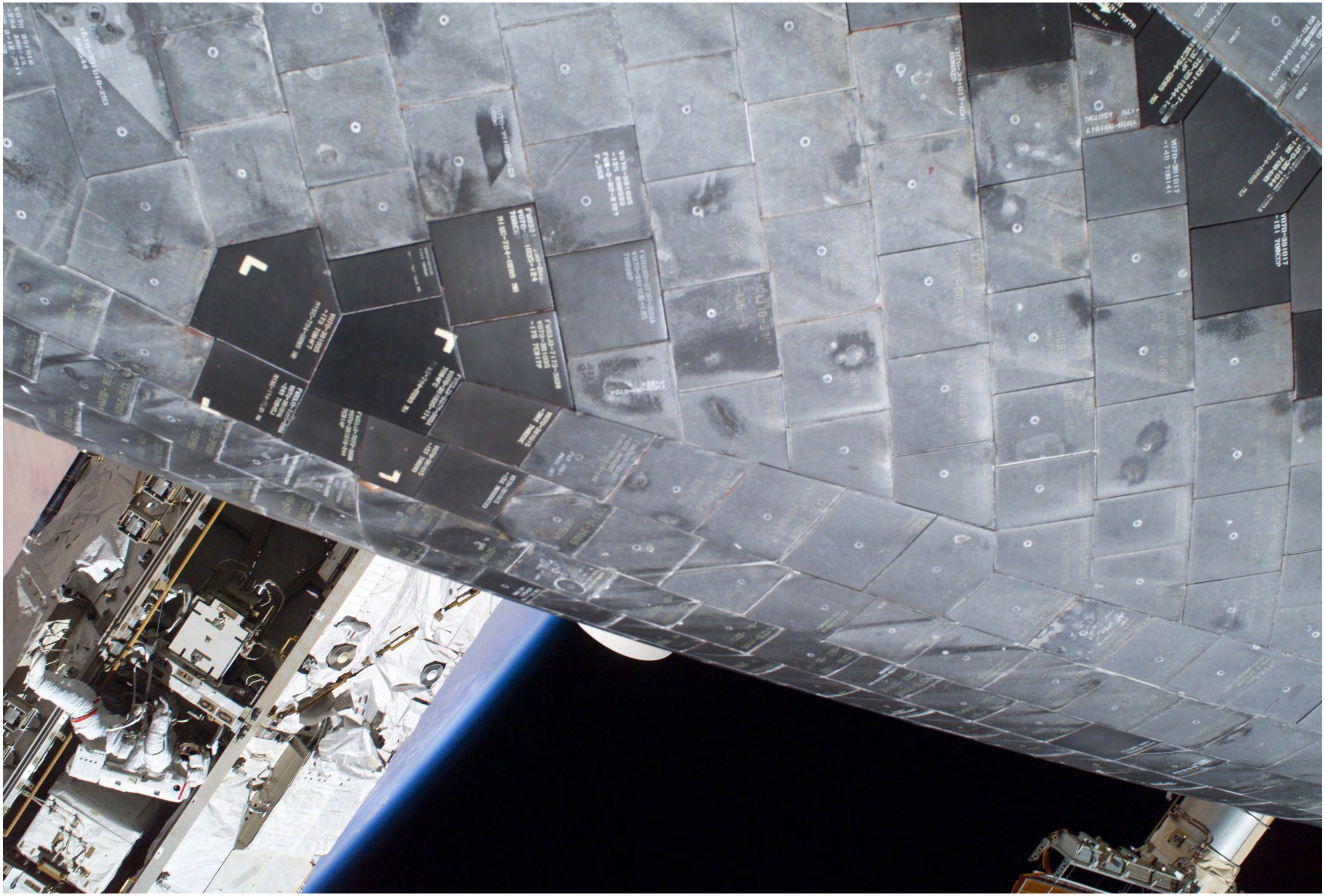
Images

Img. 1 The Space Shuttle Atlantis in orbit.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.



(Photo courtesy of NASA - www.nasaimages.org)

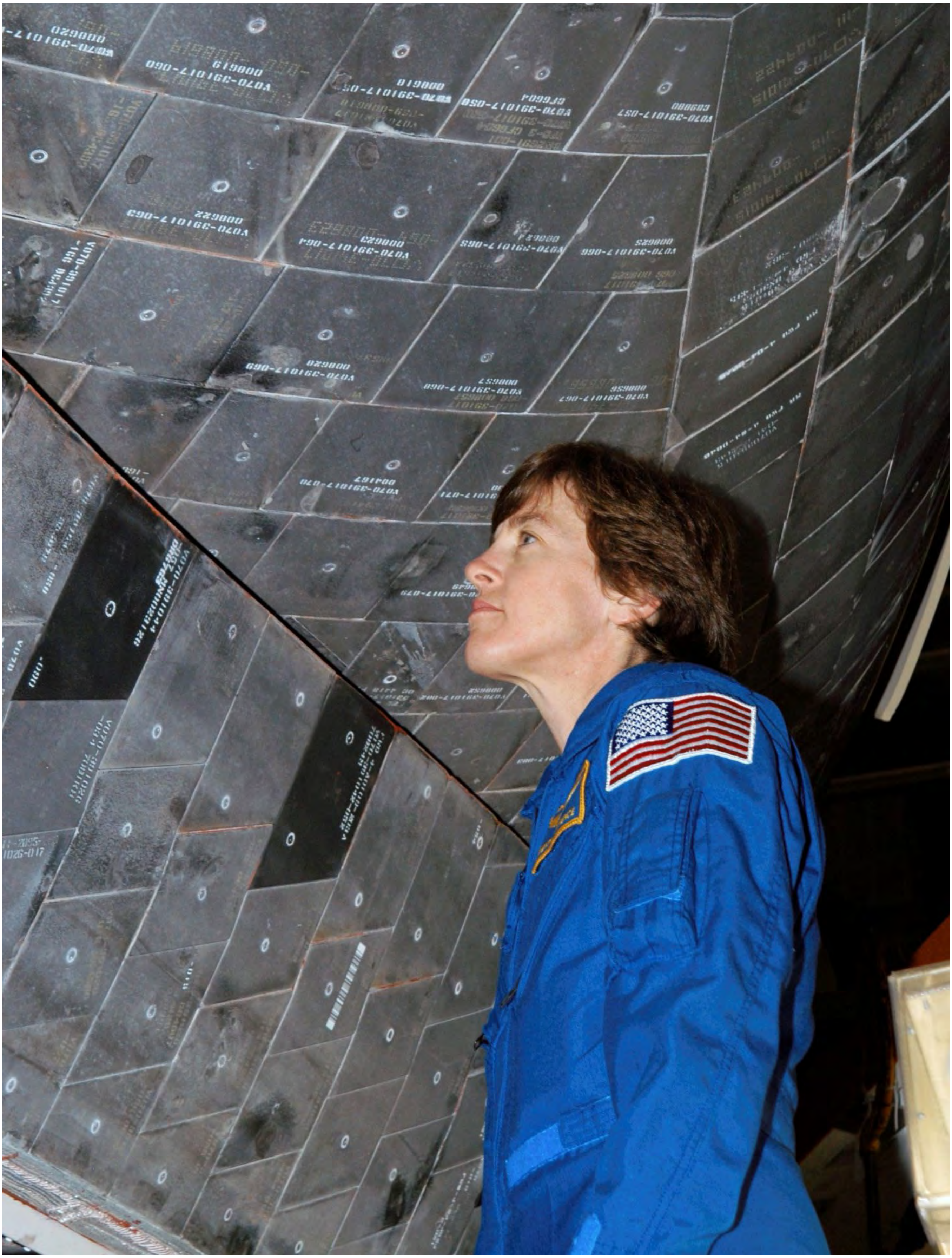
Img. 3 Replacing a shuttle tile.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 Shuttle tile showing signs of damage.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 A close-up of the tile numbering system.



(Photo courtesy of NASA - www.nasaimages.org)

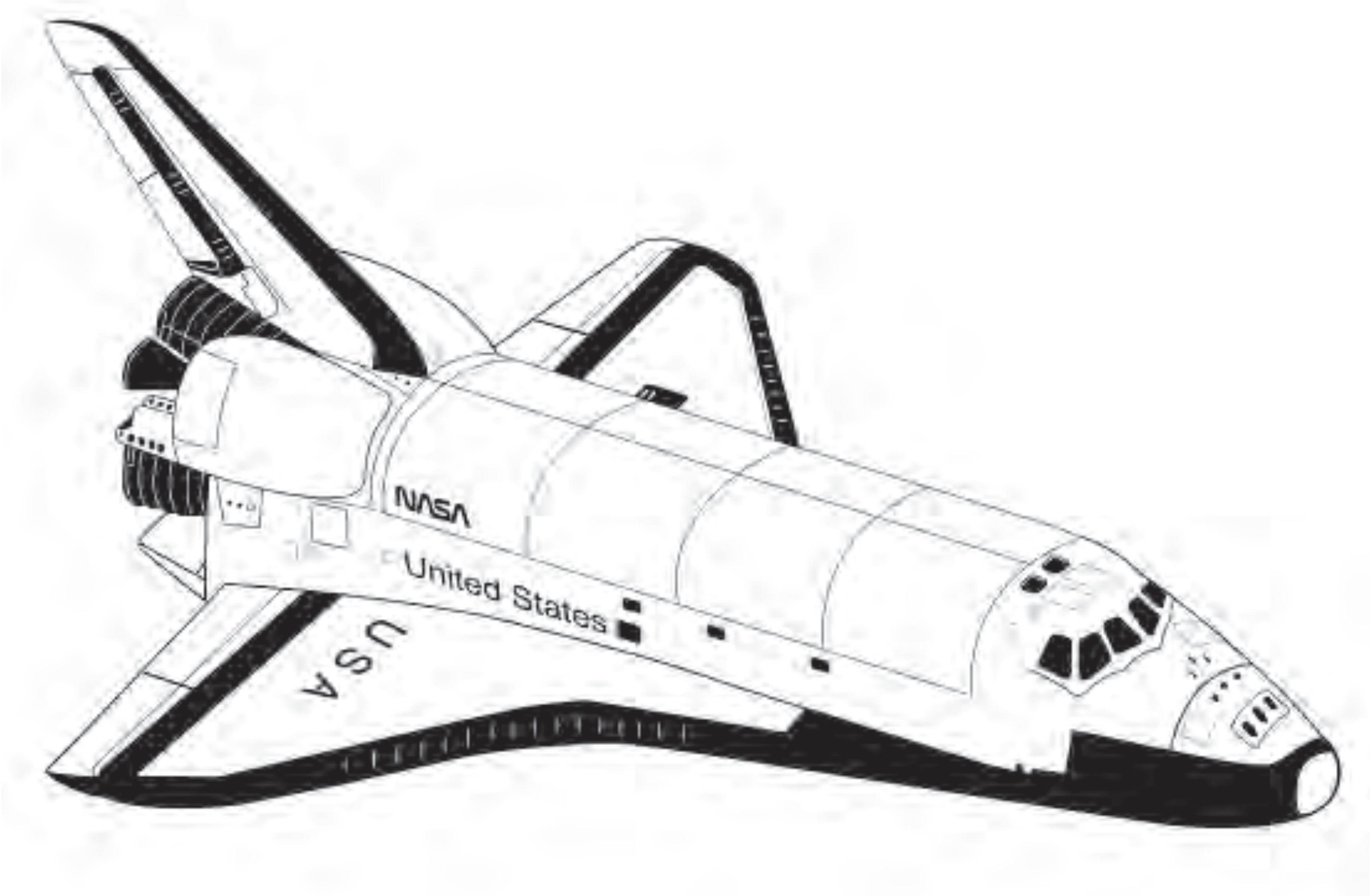
Img. 6 The underside of the Space Shuttle in orbit.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The underside of the Space Shuttle during re-entry.

(Photo courtesy of NASA - www.nasaimages.org)

Img. 8 An artist's rendering of the Space Shuttle.



(Photo courtesy of NASA - www.nasaimages.org)

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